CamBridgeSens

EPSRC Centre for Doctoral Training in Sensor Technologies and Applications

Student PhD Showcase

19 October 2017

Murray Edwards

UNIVERSITY OF CAMBRIDGE

EPSRC

Engineering and Physical Sciences Research Council

Student PhD Showcase Programme

9:00	Registration	
9:45	Talks	Oliver Bonner Josie Hughes
10:15	Flash talks	Miranda Robbins Omid Siddiqui Bogdan Spiridon Andrew Stretton Christopher Valentine Oliver Vanderpoorten Tieqiang Wang
10:45	Coffee and posters	
11:15	Talks	James Manton Franz Huber Tiesheng Wang
12:00	Flash talks	Nene Yamasaki Joseph Zammit Farah Alimagham Peter Fendt Monica Susana Covarrubias Julian Perlitz Elizabeth Gill Max Köppl
12:30	Posters and lunch	
14:00	Talks	Philip Mair Isabella Miele
14:30	Flash talks	Ye Liu Maxim Kuvshinov Ellen Hertle Pelumi Oluwasanya Chetan Poudel Fergus Riche Wenyu Wang
15:00	Coffee + posters	
15:30	Industry talks and panel discussion	Richard Williams, ioLight Tanya Hutter, SensorHut Alexandra Grigore, Simprints
16:30	Close and drinks reception	

Richard Williams
Technology Entrepreneur & Co-founder, ioLight Ltd
Commercialising Sensor Technologies - A Personal Experience

Abstract: Sensor technologies are very diverse and, more often than not, are enabling technologies that have uses in numerous applications. This 'platform' nature provides many commercial opportunities for each sensing technology which is both an advantage and a disadvantage. In this talk, Richard will use his personal experiences to describe some of the challenges in commercialising sensor technologies.

Biography: In 1995 Richard completed his PhD on applied non-linear optics at Oxford University. Then, following 3 years post doc research at Oxford, he moved to Southampton University where he was a senior research Fellow in the Optoelectronics Research Centre. At Southampton he worked on planar integrated optics and ran the multi-million pound optical fibre fabrication facility. By the time Richard left academia in 2003, he had more than 50 publications. In 2003 Richard raised funding and spun out a sensors based Company from Southampton University and was CEO of that company for 8 years. Following this Richard worked with a number of technology companies before co-founding ioLight in 2014. ioLight develops high performance portable microscopes, and began selling its products in 2016.

Tanya Hutter
Director and co-founder at SensorHut Ltd, Research Fellow at University of Cambridge
My first start-up

Abstract: In this talk I will describe my journey founding a startup company immediately after completing my PhD. I will also present the different types of funding and support that I received and describe what Cambridge has to offer to first-time entrepreneurs.

Biography: Dr Tanya Hutter is a Research Fellow at the Department of Chemistry at the University of Cambridge. Having completed her MSc at Tel-Aviv University in Material Science and Engineering, followed by a PhD in Physical Chemistry at the University of Cambridge, Tanya now leads the experimental branch of the Physical Chemistry Group. Her research focuses on chemical sensors and bio-sensors. Tanya's interests are not just in the demonstration of new science, but also in the commercialisation of new technologies. Her academic work includes collaborations with clinicians to develop and commercialise new diagnostic medical devices, and she is a founder of a start-up tech company, SensorHut Ltd.

Alexandra Grigore
Co-founder & Director of Innovation, Simprints
Biometric sensors: solving the identity bottleneck

Abstract: There are currently 1.1 billion people worldwide who have no birth certificates or any official ID. As a result healthchare professionals can not reliably identify their patients and ensure continuity of care. Simprints has created a low-cost, secure, and reliable fingerprint sensor, enabling health workers to diagnose, treat, and monitor their most remote beneficiaries. The talk will focus on technology design and manufacturing for low-resource settings and the associated challenges.

Biography: Alexandra co-founded Simprints, a nonprofit tech startup backed by USAID and DFID to develop low-cost biometric scanners to improve patient identification in developing countries. Simprints develops hardware and open-source software that can integrate into existing mobile tools. While finishing up her PhD in nanoscience at University of Cambridge, Alexandra previously worked with microfluidics, point-of-care diagnostics, biophysics and tissue engineering in Germany and the Netherlands. Her passion is bringing research breakthroughs from the lab to the field, and having a real impact on people's lives.

Flash talk and poster abstracts

Wireless Neonatal Monitoring

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The neonatal intensive care unit (NICU) can be one of the most stressful hospital environments. Alongside providing intensive clinical care, it is important that parents have the opportunity for regular physical contact with their babies because the neonatal period is critical for parent-child bonding. At present, monitoring technology in the NICU requires multiple wired sensors to track each baby's vital signs.

Parents and nurses have reported [1] that the many wires required to safely monitor the babies, creates a negative environment for parents at a critical developmental period, both in terms of physical and psychological interactions. Nurses also experience challenges with the existing system, which could negatively impact clinical care delivery.

By utilising state-of-the-art, low-power wireless transmission, we are developing a solution to remove the wires from the vital sign sensors. Working within the restrictive framework of medical device technology, a robust and secure system is proposed which is designed to meet the needs of parents, nurses, and the babies.

Figure 1. A premature baby inside an incubator in the neonatal intensive care unit. The sticker attached to the chest is one of three ECG probes. A pulse oximeter cuff is secured to the foot, and a temperature probe is attached to the baby's back. The nasal tubing provides non-invasive respiratory support.

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Sensing with Soft Robotics

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There is increasing interest in the use of soft materials in robotic applications ranging from wearable devices to soft grippers. While soft structures provide a number of favourable properties to robotic systems, sensing of large deformable soft structures is still a considerable challenge; sensors must not inhibit the mechanical properties of the soft body and the potential infinite degree of freedom deformations means that there is an intrinsically limited resolution of the sensing receptors. An approach to address these challenges using Conductive Thermoplastic Elastomer (CTPE) is proposed. This allows sensory strain information to be gained from deforming structures without disturbing the dynamics of the system enabling coverage of large soft surfaces. In this work a theoretical framework is developed which provides a set of design principles to optimize and characterise sensor implementation which allows the maximum information about location, posture and shape of the object to be determined. The proposed approach has been tested experimentally for the case study of the Universal Gripper; investigating how a sensorized gripper can allow a robot to identify grasped objects in order to enable improved gripping and manipulation performance.

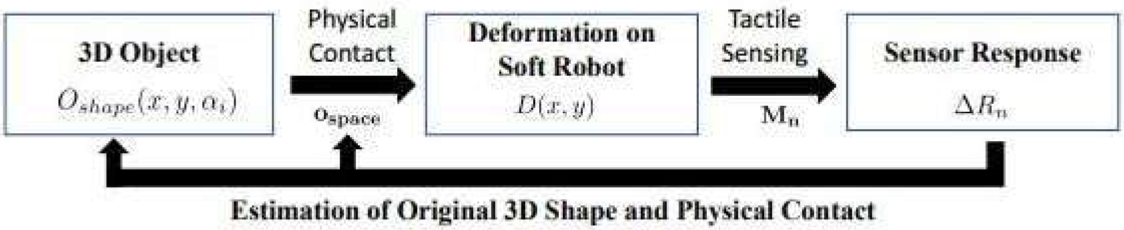

Figure 1. Concept of the framework developed. Objects in the environment lead to deformations. The proposed concepts uses the sensor responses to estimate the original 3D shape in contact with this soft body.

ASTROTIRF: total internal reflection fluorescence microscopy away from the coverslip

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High resolution is of critical importance in biological fluorescence microscopy, but fundamental optical principles limit confocal or multiphoton imaging to an axial resolution of ~600 nm. Total internal reflection fluorescence microscopy (TIRF) can be used to confine the excitation of fluorescence to a thinner region, typically around 100 nm, through the use of evanescent waves [1]. However, this thin excitation region is confined to the surface of the coverslip, preventing the observation of structure and dynamics deeper within the cell.

We propose a new method, Axial Section TRanslation Of TIRF (ASTROTIRF), to circumvent this limitation, allowing TIRF-like illumination of arbitrary sections without compromising axial resolution. By interfering multiple evanescent waves, we create excitation planes at depth, with minimal intensity at the coverslip surface. Manipulating the relative phases and amplitudes of illumination beams permits control of the axial location and extent of the illuminated plane, with ~50 nm-thick (FWHM) sections being possible within a few hundred nanometres of the interface, and 200 nm-thick sections possible up to 1 micron away from the coverslip.

In contrast to other axially-resolved TIRF methods [2, 3], we do not need to illuminate the entire sample up to the desired depth, reducing phototoxicity and photobleaching. In addition, images are produced in real time without costly computational reconstruction, and there is no requirement to bleach successive sections. We will discuss the design parameters of ASTROTIRF, its implementation, and progress made towards imaging biologically-relevant samples.

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Comprehensive Online-Characterisation of Nanoparticles by Wide-Angle Light Scattering and Laser-Induced Incandescence

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Nanoparticles from gas phase processes have gained increasing importance in research and industrial applications such as food, cosmetics or rubber industries. As the particles' functional properties like their color or their reinforcing power in elastomers strongly depend on their size and morphology a comprehensive characterisation is essential. In this work, we present a mobile measurement system [1] based on the combination of two laser-optical techniques: laser-induced incandescence (LII), which is based on the heating of nanoparticles and the detection and analysis of the subsequent thermal radiation signal, measures primary particle sizes of fractal particle aggregates [2]. Elastic light scattering (ELS) allows for the determination of size and morphological parameters [3]. Here wide-angle light scattering (WALS) is used as ELS-detection technique: An ellipsoidal mirror images scattered light from the point-wise measurement volume in its first focal point onto a CCD-chip, allowing for a single-shot acquisition of scattering data.

As light source a pulsed Nd:YAG-laser with 532 nm and 100 Hz is used for both techniques. The LII-signal is detected by photomultipliers with detection wavelengths of 400 nm and 650 nm. The WALS-mirror with a focal length of 360 mm images the elastically scattered light onto an industrial CCD-camera, resulting in quasi-continuous scattering data from 10°-165°. The scattering data can be evaluated either for effective radius of gyration and fractal dimension or for particle size distribution parameters using e.g. Bayesian inference. We will show results from combined WALS and LII measurements on soot particles as well as results from multi-variate evaluation of WALS-data.

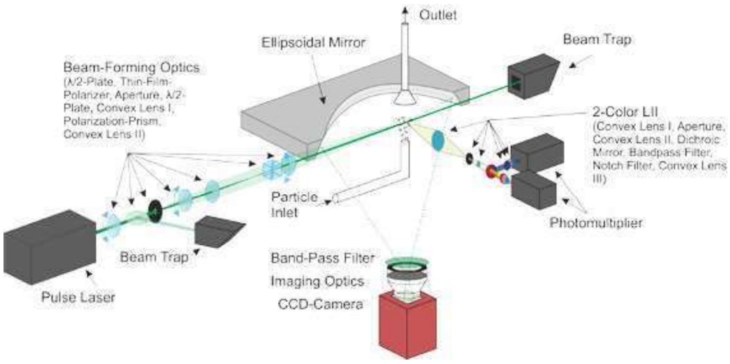

Figure 1. Schematic set-up of the measurement system combining LII and WALS.

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Candy Cane-like Semi-Interpenetrating Polymer Networks for Enhanced Power Source of Electronics

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Pseudocapacitance [1] is a material property that allows ions to enter inside the material and thus pack much more charge than carbon ones that mostly store the charge near the surface (in the so-called double layer). Conducting polymers show great promise as supercapacitor materials due to their high pseudocapacitance, low cost, toughness, and flexibility.[2] The problem with polymer-based supercapacitors, however, is that the ions necessary for these chemical reactions can only access the top few nanometers below the material surface, leaving the rest of the electrode as dead weight. Here, we use semi-interpenetrating networks (sIPNs) of a pseudocapacitive polymer in an ionically conductive polymer matrix to decrease ion diffusion length scales and make virtually all of the active material accessible for charge storage.[3] Our freestanding poly(3,4-ethylenedioxythiophene)/poly(ethylene oxide) (PEDOT/PEO) sIPN films yield simultaneous improvements in three crucial elements of supercapacitor performance: specific capacitance (182 F/g, a 70% increase over that of neat PEDOT), cycling stability (97.5% capacitance retention after 3000 cycles), and flexibility (the electrodes bend to a <200 μm radius of curvature without breaking). The supercapacitor based on our material, which is known as "Candy Cane Supercapacitor"[4], could power electronics embedded in smart clothing, wearable and implantable devices, and soft robotics.

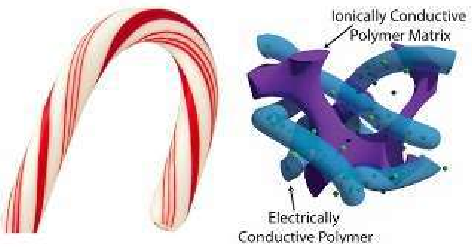

Figure 1. The nanoscaled polymer interpenetration in the supercapacitor can be imagined as the pattern commonly seen on candy canes.

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Ultrahigh-Throughput Enzyme Discovery in Metagenomic Libraries Using Droplet Microfluidics

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Enzymes are outstanding catalysts and are attractive for use in chemical synthesis. However, the number of enzymes and types of reactions available today is limited. Here we present an ultrahigh-throughput screening procedure which we used to discover novel enzymes in microfluidic droplets by tapping the vast reservoir of hidden biocatalytic potential provided by metagenomic libraries.

First, we used fluorescence-activated droplet sorting to find esterases; enzymes of industrial importance. In one experiment, we screened 16 million droplets from which we recovered 13 enzymes. These were characterised for their esterase activity and will be tested for catalytic promiscuity which is the ability to catalyse different chemical reactions, a common property in this class of enzymes.

Second, we are developing an absorbance-activated droplet screening protocol for a non-natural reaction. A substrate not usually found in nature may elicit catalysts based on promiscuous activites for new types of reactions. The chosen model reaction is the Kemp elimination, for which we established an assay in droplets. To overcome the limitation of reaction product leakage from the droplets, we present a microfluidic chip which integrates droplet making, incubation, and absorbance sorting in one device. In future, this chip will be used to screen the metagenomic library.

In conclusion, this work shows the validity and versatility of our approach which outstrips the screening capabilities of any previous metagenomic screening campaigns.

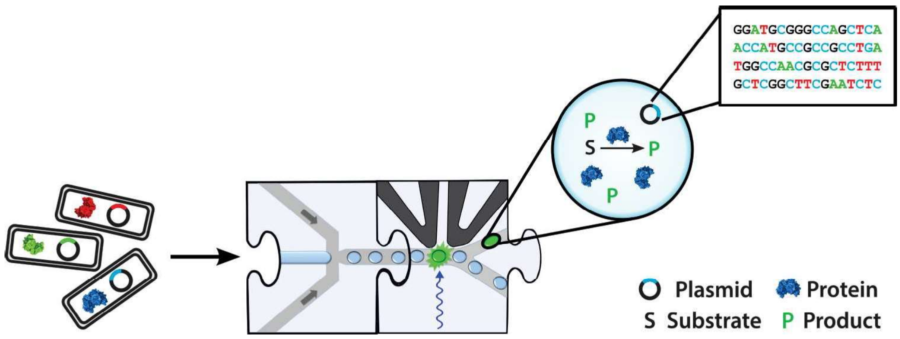

Figure 1. Single host cells expressing distinct library members are encapsulated into microfluidic droplets and sorted based on the turnover of a bait chemical into fluorescent product.

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Acoustic waveguide sensor for liquids and particle detection

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We propose a microfluidic acoustic waveguide sensor for liquid characterisation and detection of particles which utilizes surface acoustic waves (SAW) coupled resonators. The sensor is based on multiple mode conversion and coupling of SAWs at solid-liquid interfaces. The geometry consists of a microfluidic channel sandwiched between two identical piezoelectric zinc oxide (ZnO) thin films on silicon substrates. Surface acoustic waves are excited on the bottom ZnO film and detected by means of interdigital transducers (IDT) at the opposite side of the channel. The measurement of liquid properties is possible by taking advantage of the mode conversion of SAW by measuring changes in amplitude and phase of the wave at the sensing electrodes. Acoustic wave emission and its propagation through the channel containing different liquids is modelled with the finite element method (FEM) at an excitation frequency of 200 MHz. The geometry of the sensor is systematically changed by varying the height of the channel (10-30 µm) and electrode geometry to investigate the influence of liquid properties and of presence of particles on the detected acoustic waves. The sensor is the acoustic equivalent of a system of two coupled optical waveguides. The two acoustic resonators are in close proximity, and the acoustic resonant modes couple into each other as a result of the interaction of the evanescent acoustic fields, with the patterned IDTs acting as grating couplers. Finally, in analogy with optical waveguides, the coupled mode theory (CMT) is applied, in its simplest form, to the acoustic waveguide sensor and the results of the simulations are compared against theory.

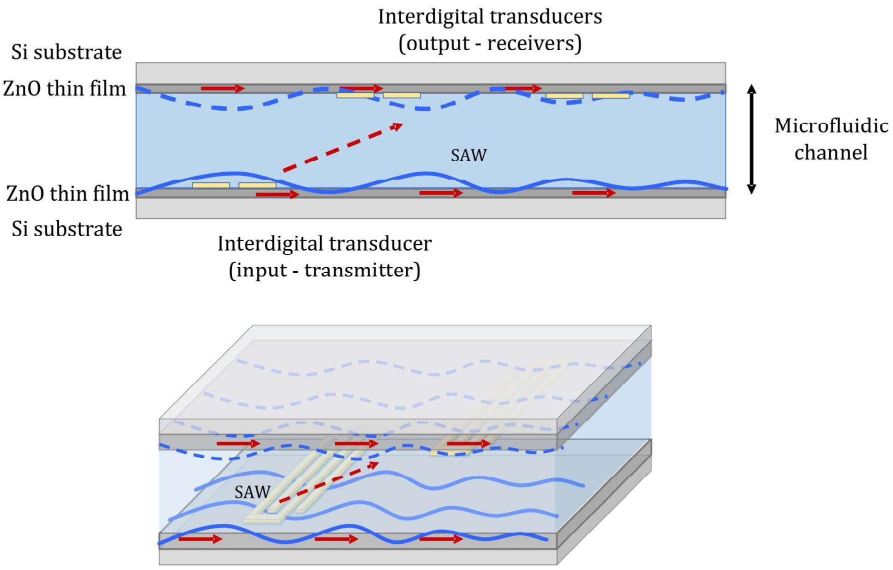

Figure 1: Diagrammatic overview of the acoustic waveguide sensor proposed

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Flash talk and poster abstracts

Untangling the Synaptic Mechanisms of Tau Trafficking

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Background: Tau pathology has been shown to progress through networks of synaptically connected neurons in Alzheimer's Disease. Early pathology occurs in the hippocampus and corresponds to symptoms of impaired spatial navigation. Though the anatomical progression is known, the synaptic mechanisms of tau transfer are not fully elucidated. A number of studies have shown that the rate of tau transfer between neurons is dependent upon neural activity [1, 2].

Aim: This project aims to understand how the frequency and intensity of neural excitation affects the rate of spread of tau pathology between synaptically connected neurons.

Method: The model system combines methods including microfluidics and electrophysiology to stimulate specific neurons, with super-resolution microscopy to observe the trans-synaptic tau transfer and the structure of tau during trafficking.

Results: Microfluidic devices have been fabricated for patch-clamp electrophysiology of fluidically-isolated neuronal populations following incubation with tau protein.

Conclusion: Hippocampal neurons are used to relate the interaction between tau trafficking and long-term changes in synaptic structures that correlate to the onset of behavioural symptoms such as impaired spatial memory.

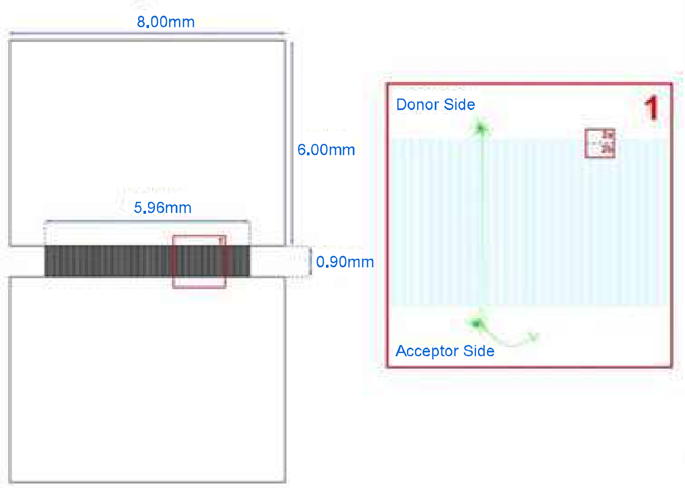

Figure 1. Design for patch-clamp electrophysiology in microfluidic devices (Image: Amanda Haack).

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Optical manipulation of nanoparticles and biomolecules

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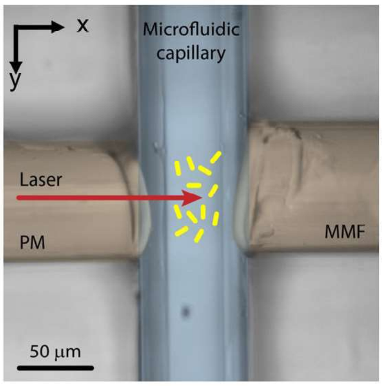
Revealing the mechanism behind β-amyloid aggregation is critical for proposing and understanding the success of aggregation-inhibiting drugs [1]. However, most of the methods used to measure aggregation restrict the free-movement of the β-amyloids by fixing them to a surface [2]. Optical and thermal forces offer a way of suspending and manipulating nanoparticles and bio-molecules in free-solution. As a first approach to understanding light-matter interactions for these nanoscale particles, plasmonic Au-nanorods resonant at 800 nm were used as a substitute for β-amyloids as they have a predefined size and spectra. A polarisation maintaining (PM) fibre delivered laser light between 730 nm – 940 nm into a micro-capillary where the Au-nanorods interaction was investigated (Figure 1a). A multimode fibre (MMF) was used to quantify and maintain a constant laser power within the micro-capillary. The scattering from the Au-nanorods were collected, from which, the velocity and brightness of every particle was quantified. Resonant-enhanced -velocities and -brightness of the Au-nanorods was observed, closely matching the Au-nanorods extinction spectra provided by the manufacturer (Figure 1b) [3]. Although the resonant enhance velocities are consistent with theory, the expected velocities are much higher than the measured velocities. This may be a result of thermal forces induced by the plasmonic Au-nanorods creating counterpropagating fluid flow.



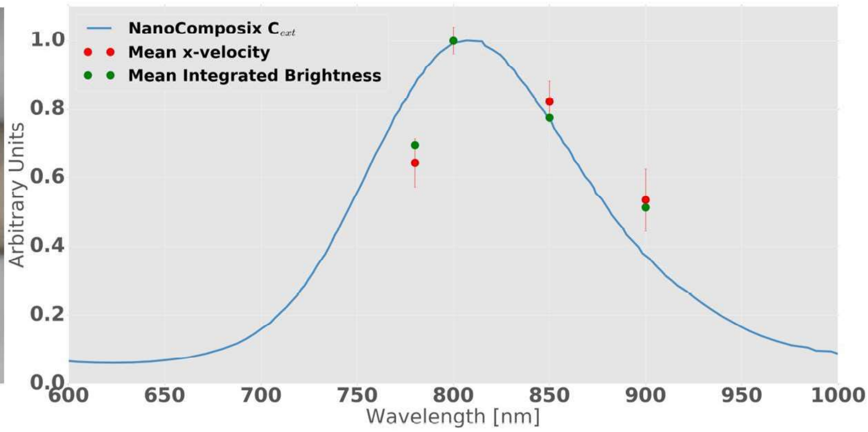


Figure 1. (a) A polarisation maintaining fibre delivering laser light into a micro-capillary where Au-nanorods are present. (b) The normal extinction spectra (C_{ext}) of the Au-nanorods closely matches the normalised mean x-direction velocity and the mean integrated brightness (equivalent to the amount of scattering) of the Au-nanorods obtained from particle tracking.

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GaN sensors for harsh environments

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Sensors are receiving unprecedented levels of interest due to their impact on many aspects of industrial systems and consumer goods. There are strong drivers for expanding the area of sensor applications to suit harsh environments. In general, these are environments in which conventional electronic sensors could not operate reliably due to excessive mechanical, thermal, electro-magnetic, or chemical stress, such as those presented in Figure 1.

Silicon, the most common material for electronic sensors, is intrinsically limited to a relatively narrow set of operating conditions outside which the circuits stop working or are even destroyed. Failure modes related to operating conditions include excessive generation of charge carriers leading to unwanted conduction and changes to the chemical composition or the crystal lattice resulting in the creation of defects and traps.

It is known that Group III-nitride (III-N) materials have outstanding semiconductor properties. For example, GaN is used successfully in a variety of high-power-, high-frequency- and opto-electronic devices. This is possible due to its wide bandgap, good mechanical strength, chemical inertness, and radiation hardness [1]. While there are numerous reports in the literature on these applications of III-N materials, the topic of sensing using these materials was reported on less often [2].

The properties of GaN and its related III-N materials indicate the possibility of matching the performance of silicon sensors in more challenging environments. In following this objective, all design levels are studied, from the fundamental physics of the materials to the performance, reliability, and system integration of the sensors. This approach opens new research paths and generates opportunities for innovation.

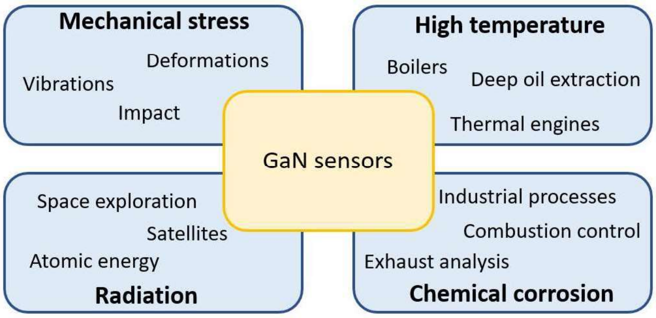

Figure 1. Application areas enabled by GaN sensors

References

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A gas sensor to measure air quality and human health

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2 EPSRC CDT Sensor Technologies and Applications
3 Alphasense Ltd, Braintree UK.
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Volatile organic compounds (VOCs) in air can provide detailed information on air quality and, when in exhaled breath, human health state. Despite growing demand for selective VOC detection, achieving desired selectivity requires complex, expensive and impractical equipment. This research seeks to develop and produce a sensor that addresses these limitations. Specifically, the project aims to combine contemporary gas separation methods with commercially available, VOC non-selective, gas sensors. In the current prototype sensor, VOCs are trapped on silica and carbon based adsorbents, eluted via controlled thermal desorption and detected with a photoionisation detector (PID). The sensor can detect and measure benzene, toluene and ethylbenzene in the tens of parts-per-billion (ppb) range, and its small size and low power requirements show considerable promise for selective VOC measurement within air quality networks and medical diagnostics. Ongoing research seeks to develop a system that is selective to a range of VOCs, with a particular focus on aromatics, aldehydes, ketones and alcohols.

2-photon lithography for microscopic lab-on-chip devices

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Misfolding of proteins inside neuronal cells is linked to Alzheimer's and Parkinson disease. The folding is on a molecular level and cannot easily be investigated with spectroscopic bulk studies nor conventional fluorescence microscopy. Two promising approaches used by researchers in this field are: The usage of lab-on-chip devices to characterize proteins "in vitro" from a biophysics point of view and fluorescence microscopy to study the protein aggregation in living cells in scaffolds "in vivo". Lab-on-chip devices are experiencing a need for nanofluidic functional features smaller than 150nm e.g for applications as nanofilters and nanonozzles to characterize and deposit proteins in even lower amounts. The length of Amyloid-β 42 (M1-42) aggregates is connected to their toxicity and integrated nanofiltration methods [1] to separate proteins in a microfluidic process pipeline are not available in biological research laboratory, unless there is access to expensive electron beam lithography systems as in clean-room facilities. Also it was shown that cell morphology and migration changes when cells are kept on cell scaffolds instead of coverslips, which underlines the need of more realistic 3D cell cultures to study e.g. the role of the protein Tau in Alzheimer's and its interplay with Amyloid-β 42. [2] [3] In order to provide researchers with both kind of devices, we investigate two-photon lithography (2PL) as nanofabrication process within biological laboratories to overcome the current microscale fabrication capabilities. We demonstrate a 2PL-system capable of producing master wafers for nanofluidic chip fabrication with channel widths of 300nm and the additional capability to 3D print cell scaffolds for "off-the-coverslip" studies of neurons.

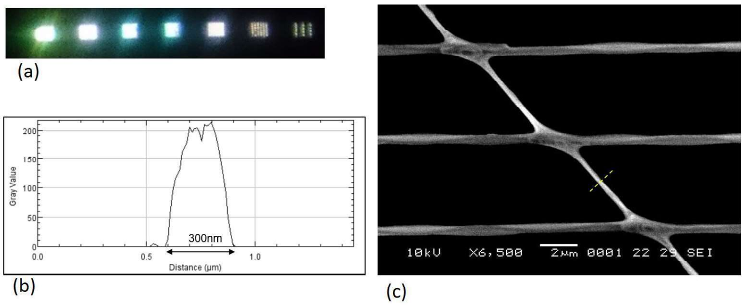

Figure 1. (a) Test patterns show optical grating characteristics; (b) Lateral profile of 2p-written line at 230µm/s and 50mW of laser power (indicated in yellow on the right); (c) SEM-image of lines written at 160µm/s and 50mW laser power; Diagonal lines were written at 230 µm/s

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Preparation and Visible Sensing Application of Plasmonic Resonance Optical Materials with Responsive Polymers as Transducer

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For decades, plasmonic nanostructures have been used as important optical sensing platforms, however, the necessity of sensitive optical instruments for detection greatly limits their practical application. Herein, a series of responsive plasmonic optical materials were prepared through introducing responsive polymer into metallic nanostructures. According to the phase transition of responsive polymer under different external conditions, the responsive plasmonic optical materials show corresponding optical properties (different colors) detectable by naked eyes, which allows these plasmonic materials to serve as sensors or indicators for visible sensing application. Importantly, these responsive plasmonic optical materials also possess excellent repeatability as well as rapid response rate. All these features make the responsive plasmonic materials attractive candidate for future optical sensing and intelligent color display applications.

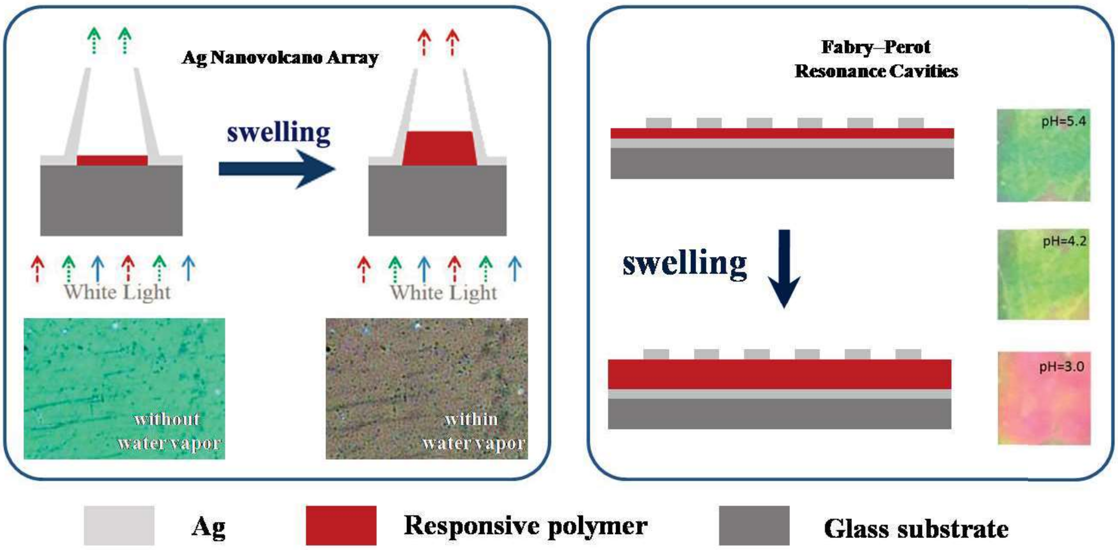

Figure 1. Two typical plasmonic optical sensing materials with responsive polymer as transducer. (left) Ag nanovolcano array and (right) Fabry-Perot resonance cavity.

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The effect of polydispersity of ultrafine aerosol particles on electrical charge measurements in low-cost sensors

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Combustion and other industrial processes generate airborne particulate matter which causes adverse environmental and health effects. Mechanistic studies have indicated that ultrafine particles (particles less than 100 nm in diameter) may have significant health impacts due to their relatively high number concentration, surface area and potential for deep penetration into the human lung. However, epidemiological evidence remains limited due to the lack of measurement networks that monitor local concentrations of ultrafine particles. We have demonstrated a low-cost, proof-of-concept device for using ultraviolet (UV) photoionization and detection electronics to yield direct, real-time measurements of total surface area of ultrafine soot particles. By varying the strength of an electric field in Figure 1, the device yields a measure of mean particle diameter and concentration.

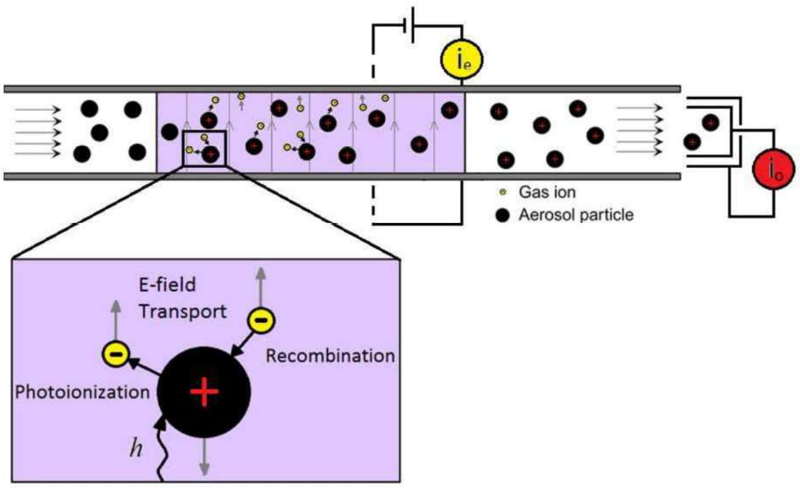

Figure 1. Ultrafine particles in continuous flow are ionized by ultraviolet light. The resulting charges are captured in an electric field to yield information on particle size, concentration and surface area

Similar devices can be experimentally calibrated with controlled aerosol sources to provide metrics such as mean particle size and total concentration from multiple electrical current measurements. However, an aerosol with a large standard deviation in particle size will provide a significantly different signal from a monodisperse aerosol with the same mean particle size. Therefore, further understanding of effect of polydispersity is required to improve the accuracy of low-cost sensors.

In this work, we solve the conservation equations for particle/ion charging and transport (convection, diffusion and electrical transport) for a laminar, steady-state, incompressible flow. Lognormal particle size distributions are represented with upwards of 100+ coupled conservation equations for multiple size bins and charge levels. Modelling results show that the effect of polydispersity on integrated electrical current can be represented by a monodisperse distribution characterized by a surface-weighted mean diameter and total concentration. Experimental and modelling results show good agreement for a range of particle distributions and operating conditions.

Towards real-time compressive sensing video links

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Current video compression standards focus on achieving high compression through computation intensive algorithms at the encoder. This is justifiable in digital video storage and in video broadcasting where the requirement is to simplify the millions of decoders served by one encoder. There is however a requirement for real-time video transmission and reconstruction from energy-constrained sensors with applications in space-borne surveillance and sensing, security surveillance in remote/harsh regions, and wireless sensor networks. These applications have sparked an interest in simple, low cost video systems that remove the complexity from the sensor nodes (encoder) to the decoder.

Compressive sensing (CS) has emerged as an alternative analogue signal processing technique which leverages the sparsity of the sensed signal, in some domain, to perform joint sampling and source coding. This leads to more efficient encoders, as the energy needed to compress the acquired images is no longer required. A major limitation of current CS reconstruction schemes is the long reconstruction time, typically of the order of tens of seconds. This makes real-time video links, which dictate a reconstruction time of at most 41ms per image, unrealisable.

In our work, we introduce a novel CS image sampling and reconstruction scheme that rivals current state of the art in image quality, whilst reducing the reconstruction time to 14ms allowing for real-time applications (figure 1). Future work will pave the way for efficient real-time CS video links.

a. Original Image

(b) Current state of the art [3]. PSNR = 31.44, SSIM = 0.680. Reconstruction time = 10min+

(c) Proposed scheme. PSNR = 34.85, SSIM = 0.660. Reconstruction time = 14ms.

Figure 1. Reconstruction of the 256x256 image 'Parrots' using current state of the art CS image reconstruction scheme (b) and the proposed scheme (c).

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Integration of Optical Spectroscopy with Microfluidics for Detection of Organic Compounds to aid Traumatic Brain Injury

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Traumatic brain injury (TBI) is a major cause of death and severe disability in all age groups, particularly in children and young adults. Following the primary TBI event, secondary processes occur within the following hours and days which can adversely influence patient outcome if not immediately identified and treated accordingly. Continuous monitoring of clinically-relevant metabolite concentrations within the extracellular cerebral fluid has the potential for early detection of metabolic derangements, thus enabling adequate patient treatment [1, 2]. The current clinically-implemented system, based on enzymatic detection, only allows hourly monitoring while also being unreliable, costly and labour intensive. This research focuses on the development of a low-cost, compact clinical sensing device to allow continuous analysis of the brain chemistry of patients suffering from TBI and careful monitoring of their progress (figure 1). Several device prototypes in different configurations (transmission and reflection modes) have been designed and fabricated by integrating mid-infrared spectroscopy, using fibre-optic and waveguide technology, with microfluidics. Extensive work is currently being carried out to understand and establish the most clinically feasible prototype in terms of hardware and signal-to-noise ratio, to subsequently be implemented in clinical trials.

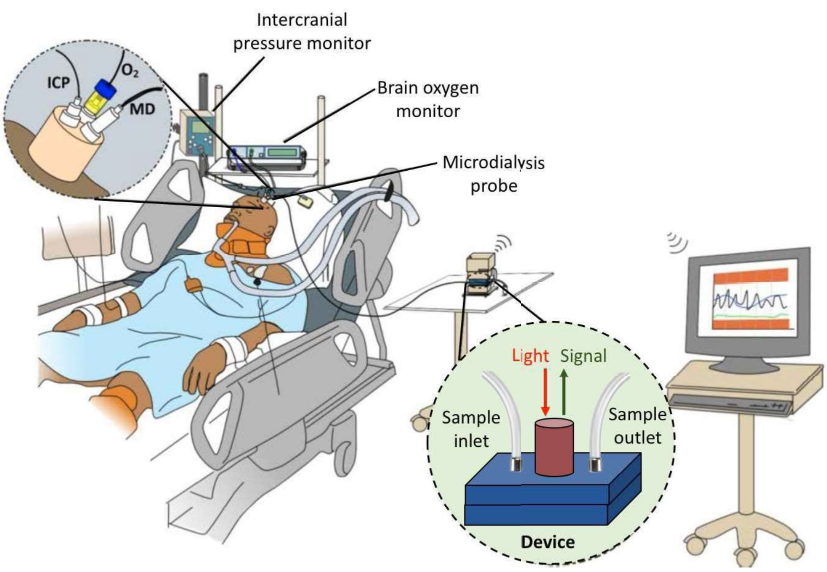

Figure 1. TBI patient in the neurocritical care unit, undergoing monitoring of brain chemistry changes using the proposed optical sensing device. Adapted from [3].

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Multiparameter correlation and uncertainty analysis for a high-speed near-infrared broadband absorption spectrometer

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In combustion applications, non-invasive measurement technologies for the detection of temperature, species concentration and pressure are of great interest as effects on flame propagation, flow and temperature fields can be avoided. Internal combustion (IC) engines represent a challenging environment, additionally detection rates in the kHz-range are required. One technology which has shown great potential to meet these requirements is supercontinuum absorption spectroscopy [1,2]. Based on a broadband laser light source and a spectrometer containing a near-infrared high-speed line-scan camera as a sensor, it allows for the simultaneous multiparameter-detection in a wide temperature and pressure range (tested up to 1900 K and 65 bar [2]). The measurement data analysis is performed by a least square nonlinear curve fitting algorithm, which minimizes the residuals between the measurement based H_2O absorbance spectrum and a simulated parameter dependent absorbance spectrum.

However, the accuracy and precision of the measurement data analysis are limited by multiple sources of error, one of these is camera noise. Within this study, we evaluate simulated noisy H_2O absorbance spectra to estimate the uncertainty of the parameter evaluation and reveal correlations between the parameters for two typical IC engine conditions (before/after combustion). For this purpose, a transmission signal intensity dependent camera noise model based on experimental data is generated. Simulated transmission signals within the absorbance model with known exact solutions are then superimposed by the camera specific noise. The Jacobian matrix received from the curve fitting algorithm reveals the temperature, species concentration and pressure uncertainties and furthermore correlations between these parameters. It is shown that that the uncertainties in the compression-phase significantly decrease after combustion occurs and that there exists an apparent correlation between pressure and species concentration.

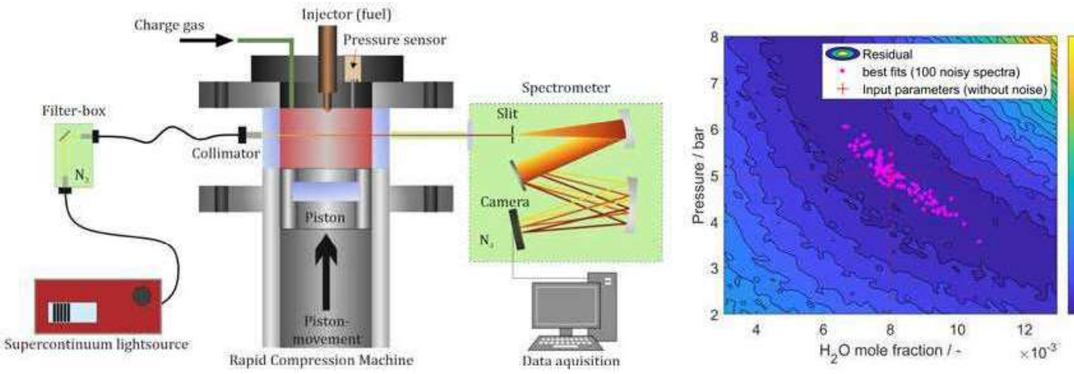

Figure 1. Experimental setup for the transmission signal detection (left) and contour plot for residual in absorbance with variable pressure and H_2O concentration showing the best-fit distribution for 100 noise superimposed spectra (right).

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[1] Werblinski, T., Kleindienst, S., Engelbrecht, S., Zigan, L. and Will, S., "Supercontinuum based absorption spectrometer for cycle-resolved multiparameter measurements in a rapid compression machine," Appl. Opt. 55, 4564-4574 (2016)

[2] Werblinski, T., Fendt, P., Zigan, L. and Will, S., "High-speed combustion diagnostics in a rapid compression machine by broadband supercontinuum absorption spectroscopy," Appl. Opt. 56, 4443-4453 (2017)

BIO-BASED EPOXY RESINS FROM LOW TO HIGH Tg

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Vegetable oils is a suitable option for the production of polymer composites that incorporate inorganic and organic particles and fibers, both synthetic and natural in origin, and sized from the macro to the micro and nanoscale[1]. Vegetable epoxidized oils as epoxidized linseed oil (ELO) have ability to replace the conventional petroleum-based epoxy resin such as DGEBA, DGEBF.
The epoxide group containing vegetable or nonvegetable oils shows a reactivity similar to petroleum-based epoxy resin when anhydride is used as curing agent. It is important to note that mechanical properties as thermal like *T*g, and morphological properties not only depend on resin but also on type of curing agent[2], epoxy/amine ratio and conversion of reaction. Tg's below 50°C are obtained for the epoxidized oil and a maximum of 127°C by using anhydride systems[3]. To increase the Tg, different types of bio epoxy hardener were mixed with ELO to obtain high conversion and high Tg (>70°C). Also, the effect of PEO homopolymer in the resin was evaluated. Conversion of the reaction and Tg were studied by DSC and MTDSC. MTDSC is a versatile technique to characterize multicomponent systems by separating a signal in reversible and non-reversible heat flow.

Figure 1. Epoxidized linseed oil structure

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Multiparameter correlation and uncertainty analysis for a high-speed near-infrared broadband absorption spectrometer

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[1]Lehrstuhl für Technische Thermodynamik (LTT), FAU Erlangen-Nürnberg, Germany
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In combustion applications, non-invasive measurement technologies for the detection of temperature, species concentration and pressure are of great interest as effects on flame propagation, flow and temperature fields can be avoided. Internal combustion (IC) engines represent a challenging environment, additionally detection rates in the kHz-range are required. One technology which has shown great potential to meet these requirements is supercontinuum absorption spectroscopy [1,2]. Based on a broadband laser light source and a spectrometer containing a near-infrared high-speed line-scan camera as a sensor, it allows for the simultaneous multiparameter-detection in a wide temperature and pressure range (tested up to 1900 K and 65 bar [2]). The measurement data analysis is performed by a least square nonlinear curve fitting algorithm, which minimizes the residuals between the measurement based H_2O absorbance spectrum and a simulated parameter dependent absorbance spectrum.

However, the accuracy and precision of the measurement data analysis are limited by multiple sources of error, one of these is camera noise. Within this study, we evaluate simulated noisy H_2O absorbance spectra to estimate the uncertainty of the parameter evaluation and reveal correlations between the parameters for two typical IC engine conditions (before/after combustion). For this purpose, a transmission signal intensity dependent camera noise model based on experimental data is generated. Simulated transmission signals within the absorbance model with known exact solutions are then superimposed by the camera specific noise. The Jacobian matrix received from the curve fitting algorithm reveals the temperature, species concentration and pressure uncertainties and furthermore correlations between these parameters. It is shown that that the uncertainties in the compression-phase significantly decrease after combustion occurs and that there exists an apparent correlation between pressure and species concentration.

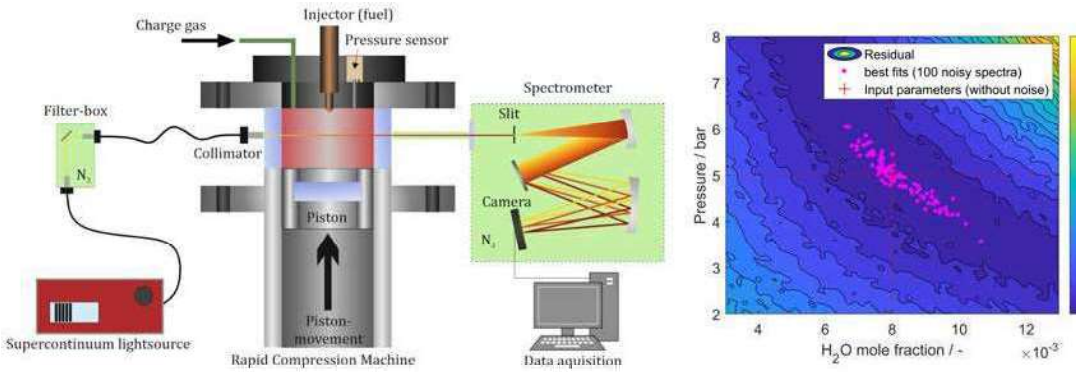

Figure 1. Experimental setup for the transmission signal detection (left) and contour plot for residual in absorbance with variable pressure and H_2O concentration showing the best-fit distribution for 100 noise superimposed spectra (right).

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3D Layer-wise Biomaterial Fibre Patterning on an Additive Manufacturing Platform

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We present a low voltage electrospinning patterning (LEP) technique for fabricating biomaterial fibril patterns at micron to submicron resolution. We have translated our original configuration to an additive layer-manufacturing platform on a commercial 3D printer, modified in-house, for substrate flexibility and greater versatility of fibre placement. We demonstrate the ability to place 3D fibril architectures of gelatin, at a height of up to 8mm with fibres deposited as variable heights and orientations. The printed fibres that can be taut or loosely suspended, are in the range of 1-10 microns and have an inter-fibre spacing of 100 microns. This extends from the printed fibre resolution that conventional extrusion-based 3d printers are capable of. Our system has the capability to switch between conventional fused filament fabrication (FFF) of thermoplastics and LEP biomaterial patterning to embed multiple layers of taut fibres within a thermoplastic mould.

The creation of designable 3D fibril architecture has applications in several diverse fields of research including tissue engineering, electronics and energy storage. We envisage it applied to biomimic the fibril component of an extracellular matrix whilst co-ordinating the deposition of cell laden hydrogels via 3D bioprinting. This serves to enhance the biofunctionality of 3D bioprinted tissue constructs for in vitro disease modelling and drug screening platforms.

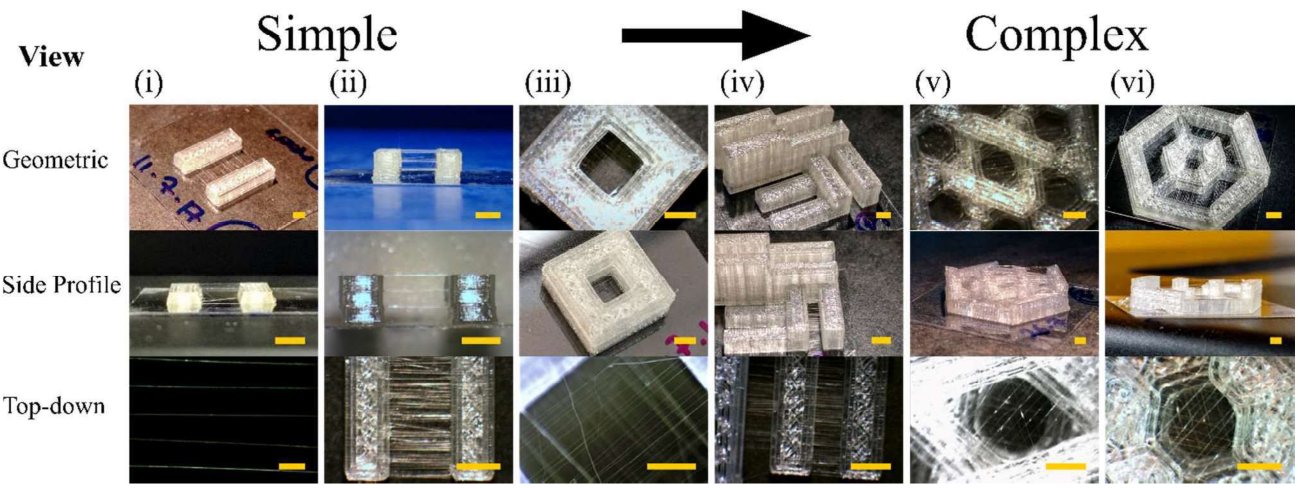

Figure 1. 3D Fibril structures of varying complexity. Scale bars represent 2mm, aside from top-down views in (i) 100µm and (iii) 1mm.

Fiber-optic Temperature Measurement Based on Fiber Bragg Gratings and Spontaneous Raman Backscattering in a Single Fiber

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Fiber-optic temperature sensors exhibit a range of unique features which make them indispensable for various industries. One of the most important characteristics is probability the immunity against strong electric and magnetic fields that make these sensors predestined for monitoring applications in power energy sites.

A range of sensor systems is commercially available, however, each of these systems relies on only one measurement principle such as fiber Bragg gratings (FBGs), Rayleigh, Brillouin or Raman scattering. Naturally, each principle has advantages but also downsides. FBGs offer a good precision but also cross-sensitivity to strain and can only measure temperature at distinct spots whereas the approaches based on scattering (Raman, Brillouin or Rayleigh) allow distributed temperature sensing (DTS) along the fiber at the cost of a limited temperature or spatial resolution.

We have developed a fiber-optic temperature measurement system that combines two approaches, FBG temperature sensors and Raman based DTS, to overcome these limitations. Deploying a technique known as incoherent optical frequency domain reflectometry (IOFDR) we can perform spatially resolved measurements of backscatter/reflections and therefore multiplex several FBG sensors at the same wavelength in one sensor fiber [1] and relate the Raman backscatter signal to specific fiber segments.

In our lab we have demonstrated combined temperature measurements along a 50 m long HI1060 Flex fiber with six FBGs over a temperature range from -20 °C to +80 °C [2]. We have seen good agreement between the FBGs temperature results and the Raman DTS which achieved a mean standard deviation of 1.5 K at a spatial resolution in the order of 1 m.

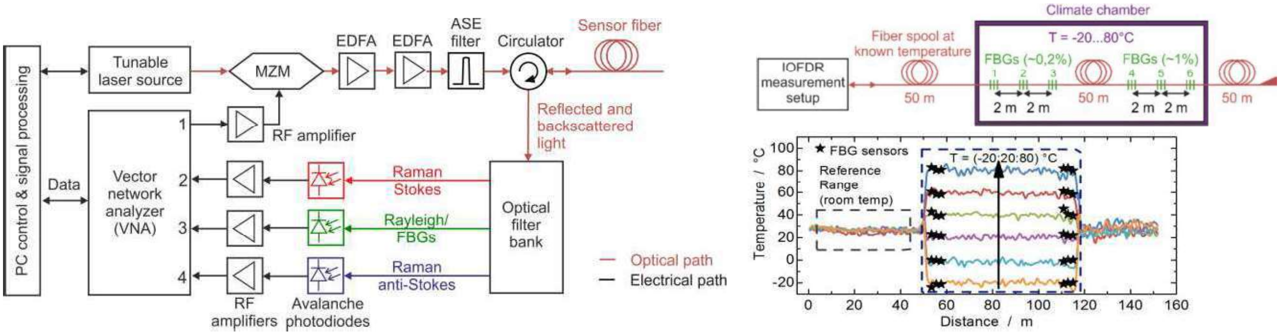

Figure 1. IOFDR measurement setup (left), experimental setup of sensor fiber and measurement results (right)

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Vapor Induced Phase Separation in Low-Voltage Continuous Electrospinning Patterning

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Low-Voltage Continuous Electrospinning Patterning (LEP) is a micro- and nano-fiber fabrication technique with improved precision and controllability. Here, we demonstrate that Vapor-Induced Phase Separation (VIPS) is a simple and cost-effective way to create sub-micron structures within a polymeric material. By generating a temperature gradient, we observed VIPS phenomenon in polystyrene (PS) films and electrospun fibers. Micro-pores were introduced onto the surface and within the PS films and fibers, resulting in a set of changes in material properties such as transparency and roughness. Therefore, LEP coupled with VIPS may have implications for the design of nanofibers with tunable texture and a close resemblance to the native extracellular matrix (ECM). The as-spun fibres created by LEP-VIPS can be used as tissue engineering scaffolds, especially for studies on topography-guided cell behaviour.

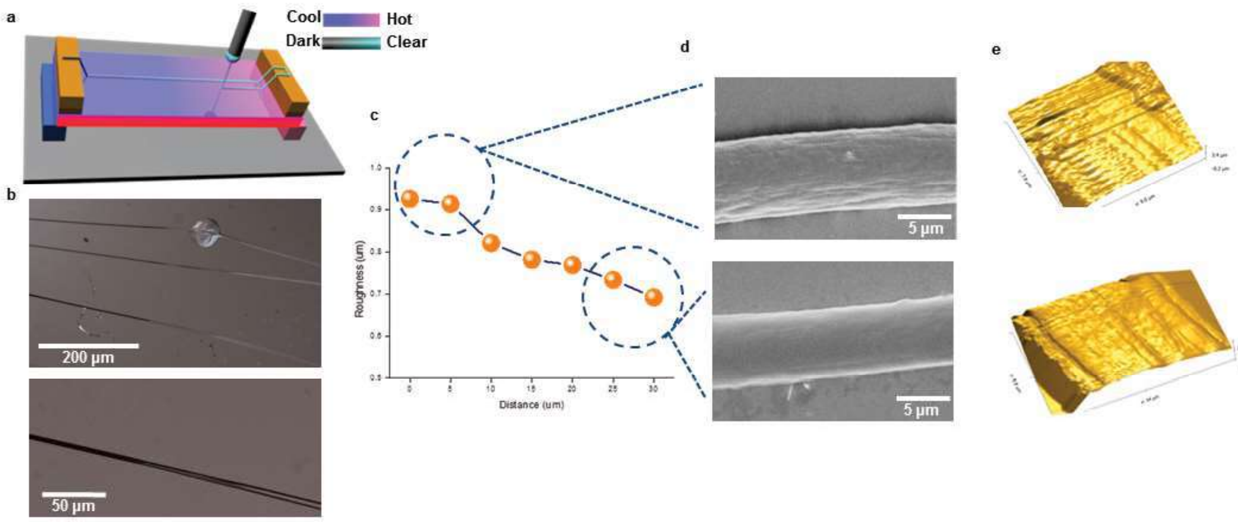

Figure 1. Transparency and surface roughness of LEP-VIPS PS fibers. (a) Schematics of LEP coupled with VIPS. (b) VIPS PS fibers showed high transparency at heated side (right) but low transparency at cool side (left) under an optical microscope. (c) Change in roughness along one PS fiber. (d) Surface morphology of rough and smooth parts in a PS fiber under a scanning electron microscope. (e) 3D surface texture of rough and smooth parts in a PS fiber under an atomic force microscope.

Elastic and Raman Scattering techniques for CNT synthesis

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We are developing techniques for understanding the process of carbon nanotube (CNT) synthesis in high temperature reactors using the floating catalyst in the chemical vapour deposition technique. Two optical techniques are currently being considered for detecting and identifying the gas-phase species and the process of particle agglomeration and formation.

Cavity Enhanced Raman Spectroscopy is being developed where the enhancement of the Raman scattered signal is achieved by using an external optical cavity made of two highly reflective mirrors whilst using low power diode lasers (<0.1 W) [1]. The technique will allow detection of a range of species of interest in the process (methane, hydrogen, thiophene, ethanol, ferrocene) to improve the understanding of the process of precursor decomposition and transformation into particles. Preliminary experiments show that it should be possible to obtain finesses of the order of 10^3, which would lead to significant Raman signal enhancement and therefore enable Raman signal detection using this spectrometry technique [2].

Angle-resolved elastic light scattering (ELS) is being pursued to investigate the particle formation *in situ*. The theory of small angle scattering (ELS) allows the determination of the mean geometric particle properties, such as radius or length, from the relative scattered intensity as a function of the scattering vector [3]. Validation experiments show that it is possible to determine sizes of particles *in situ* down to 100s of nanometres in feature size [4].

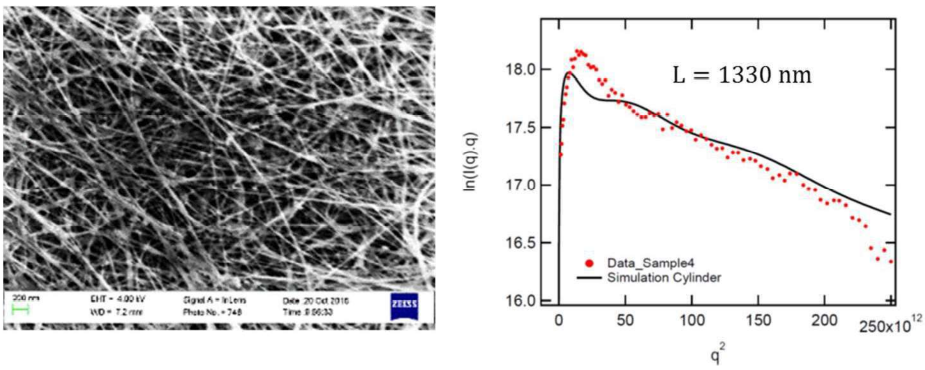

Figure 1. Determination of CNT bundle sizes via SEM and ELS

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Temperature measurements using laser-induced phosphorescence of luminescent particles

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The optimization of most processes in engineering and energy technology requires the determination of temporally and spatially resolved temperature fields. Thermographic phosphor particles cover a broad temperature range [1,2] and they may be applied for both surface and gas phase temperature measurement. In gaseous flows, phosphor particles can also function as PIV tracers to determine flow velocities simultaneously [3].

The luminescence emission characteristics and the thermal sensitivity of the phosphor material is strongly dependent on a variety of influencing factors such as dopant type and concentration, host matrix, particle size or chemical and physical environment. Therefore, a precise calibration and an investigation of potential systematic errors are indispensable. This work concentrates on the characterization and optimization of the high temperature phosphor YAG:Dy^{3+}. Special emphasis was placed on the effect of the activator and sensitizer concentration as well as the influence of the host matrix.

Samples of $Y_3Al_5O_{12}$ (YAG) and Y_2SiO_5 (YSO) with Dy^{3+} as the dopant ion were synthesized by solid-state method, changing the dopant concentrations from one to three percent. Additionally samples with two different sensitizers, namely Tm^{3+} and Pr^{3+}, were produced using the same method. Emission measurements were conducted in a high-temperature oven for temperatures from 300 K to 1600 K. The samples were excited by the third harmonic of a pulsed Nd:YAG laser. Emission spectra were measured using a spectrometer, and lifetime data was collected through two high speed photodiodes and an oscilloscope.

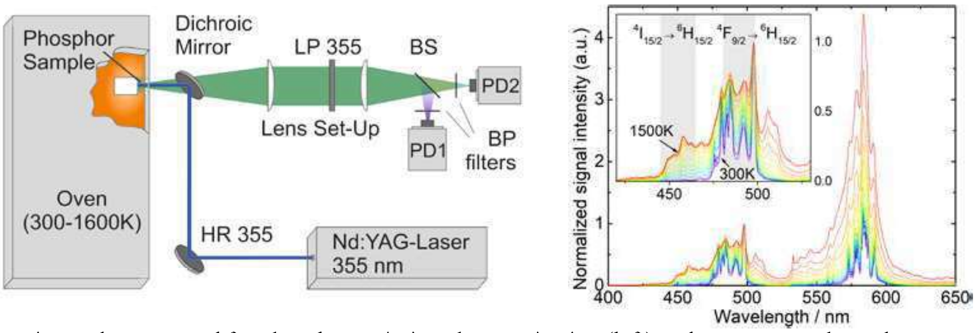

Figure 1. Experimental set-up used for phosphor emission characterization (left) and temperature dependent spectral emission behavior of YAG:Dy^{3+}.

The spectral temperature determination is based on the two-colour intensity ratio approach, analysing the emission of two closely spaced high energy levels. The ratios display a similar trend for all samples, with higher sensitivity of the YSO:Dy^{3+} samples but higher quenching temperatures of the YAG:Dy^{3+} samples. The decay time decreased with increasing activator concentration and for all codopings. Since codoping YAG:Dy^{3+} by Tm^{3+} decreased signal intensity considerably, it is not suitable sensitizer. In contrast, codoping with Pr^{3+} resulted in improved luminescent characteristics. The decay time of YSO:Dy^{3+} decreased by 60 % compared to YAG:Dy^{3+} with slightly lower absolute intensities.

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Particulate Matter (PM2.5) Detection and Monitoring.

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Exposure of human beings whether old or young individuals to Particulate Matter (PM) pollution has been shown to have detrimental health effects, mostly cardiovascular. Researchers worldwide seek the constituent of PM having diameter less than 2.5 microns ($PM_{2.5}$) with the most dangerous effects by identifying PM constituents collected during epidemiological studies and prior knowledge.

Detection and monitoring of $PM_{2.5}$ has been most successfully done with large, expensive gravimetric equipment in air quality monitoring centres. The static networks they form cannot provide spatial and temporal resolution needed to correctly model pollution. Light scattering based methods most commonly used in the more portable, less expensive PM sensors need recalibration as they tend to deviate from unit to unit. Other techniques have been used that cannot be miniaturised.

The important task of $PM_{2.5}$ detection via capacitive method is presented here. Previous work [1] on this method have only succeeded in detecting particles of size PM_{10}. We present the design, simulation, fabrication and preliminary test of a capacitive-based $PM_{2.5}$ sensor.

The simulation was done using COMSOL finite element analysis tool, the fabrication was done using conventional lift-off lithography techniques and preliminary tests were carried out in an indoor environment. The results obtained so far have shown that the sensor works. For a 5-electrode interdigitated combs set-up, a clear signal is observed, especially as the particle moves closer to the sensor surface (Figure 1). For the preliminary test, a signal large enough to be read using a simple multi-meter is observed. Future work characterisation of the sensor in appropriate environment.

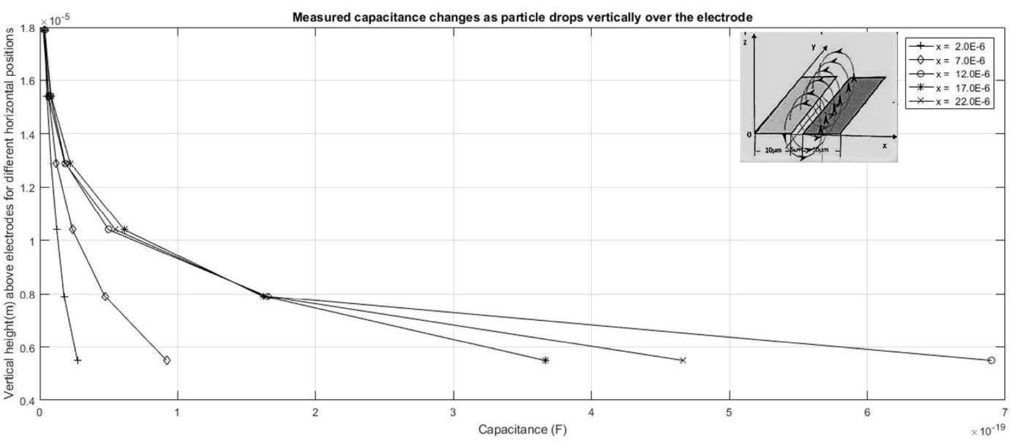

Figure 1. Measured capacitance as particle drops vertically towards the electrodes surface from different horizontal positions.

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Supercontinuum sources for biological imaging: automated, high-content, drug screening platforms

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The introduction of fast pulsed supercontinuum radiation sources has revolutionized the field of imaging for biological and medical research. In this poster, we demonstrate the advantage of supercontinuum features like broad bandwidth, high-brightness, pulsed output and spatial coherence in fluorescence imaging applications. We focus particularly on our progress in building a bespoke, automated, wide-field imaging platform that incorporates supercontinuum sources for illumination. When completed, the instrument will provide a unique capability to image cells in an unsupervised fashion with high-throughput and high-content at sub-cellular resolution. Each image will contain multidimensional information resolving excitation/emission spectra, lifetime and anisotropy of the fluorescence markers or biosensors. The collection of high-content data will facilitate targeted or exploratory studies for drug-screening or probing protein-protein interactions. Using our current setup, we report promising results showing differences in protein aggregation profiles in live worm models of Alzheimer's and Parkinson's diseases.

Core-shell electrospinning of highly conductive and flexible micro/nano silver fibre

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Metallic fibre of micro to nano scale are essential for fabricating embedded electronic textile, flexible sensors with high transparency and bioelectronic device. Electrospinning is an efficient additive manufacturing method to produce micro/nano fibre, and it has unique advantages in achieving the optimized combination of fibre properties. This research focuses on using Core-shell Low-voltage Electrospinning (Co-LEP) technology to deposit highly conductive silver fibre in micro/nano scale. Co-LEP is a one-step process to manufacture highly aligned silver fibres under mild conditions, such as low external voltage (<400V) and low temperature (<90℃). My work demonstrates the capability of printing suspended core shell silver fibres in micro to nano scale. Figure 1a is an SEM global image of suspended fibres and Figure 1b shows the core shell structure of the fibre in detail. Suspended conductive fibres can be used to assemble textile sensors, as the fibres could connect with substrate well (Figure 1c). Fibres demonstrate desirable mechanical properties similar with human skin, such as strength and flexibility. In summary, this Co-LEP technique reported here should open up new avenues in the patterning of bio-/ electronic- elements, and free-form nano- to micro-scale fibrous electronic structures.

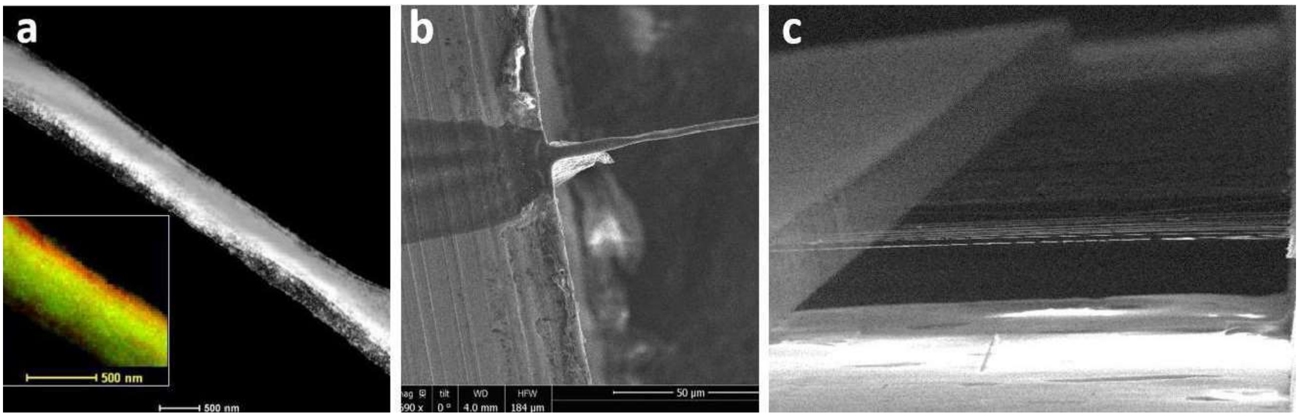

Figure 1. a) Global SEM image of suspended silver fibre. b) TEM image and EDX analysis of silver core shell fibre. c) SEM image of connection area of the silver fibre..

Nanoimprinted surface relief Bragg gratings for sensor applications

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Bragg gratings represent promising optical sensor elements for lab-on-a-chip systems, providing signals with a low dependency on noise [1, 2]. For this work, three-dimensional surface relief Bragg gratings (SRBG) were structured on planar silicon waveguides using focused ion beam (FIB) milling. For the one step replication of the combined micro- and nanostructured sensing elements substrate conformal imprint lithography (SCIL) was employed [3]. After molding a PDMS stamp, imprints into OrmoComp®, a promising material for optical device fabrication [4], were performed. Successful structure transfer was achieved on full wafer level (wafer diameter of 100 mm). Optical measurements were conducted using an interrogator system, operating in the telecom wavelength range from 1510 nm to 1590 nm. Temperature measurements were performed on a hotplate by heating the sample in steps of 5°C from room temperature to 50°C, while simultaneously monitoring the reflected Bragg wavelength. Imprinted SRBGs with 2 mm grating length showed narrow banded reflection signals with a -3dB-bandwidth of down to 422pm. The temperature sensitivity of the investigated SRBGs was determined to be 202 pm/°C, which is about 20 times higher compared to silica based sensors [2]. Further on, the sensitivity of the Bragg grating sensor towards refractive index changes in the surrounding medium was demonstrated for different aqueous solvents and index matching liquids. Additionally, the surface functionalization of OrmoComp®-SRGBs was shown by a successful deposition of SiO_2- and TiO_2-layers.

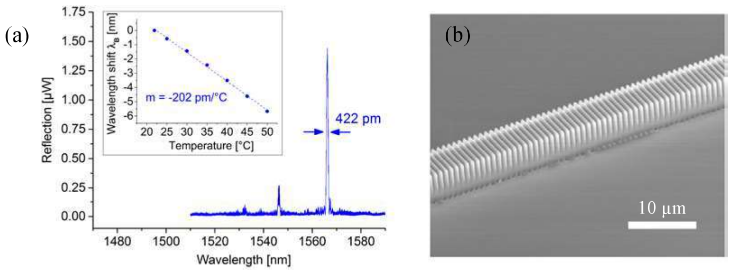

Figure 1. (a) Reflection spectrum of a surface relief Bragg grating imprinted into OrmoComp®. The inset shows the temperature sensitivity of such a sensor, with the relative shift of the reflected Bragg wavelength being plotted as a function of the sample temperature. (b) SEM-image of an imprinted OrmoComp®-waveguide with a surface relief Bragg grating.

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A NOVEL COMPACT MULTIPHOTON ENDOMICROSCOPE WITH ELECTRICALLY TUNABLE FOCUSING OPTICS TO ASSESS TISSUE ENDOGENOUS OPTICAL BIOSENSORS

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KEY WORDS: Multiphoton Microscopy, Endomicroscopy, Label-free Imaging, GRIN Objective, Electrically Tunable Lens

Multiphoton Microscopy (MPM) is widely applied for live tissue imaging, providing greater imaging depths and higher resolution in scattering tissues than standard microscopy techniques [1]. Based on Multiphoton Excitation (MPE) of endogenous fluorophores acting as optical tissue biosensors (NADH, FAD and collagen), many details of the tissue morphology can be visualized without any staining with fluorescent markers [2]. Label-free multiphoton imaging enables, for example, visualization of inflammation related changes in the colon in inflammatory bowel disease. Thus, endogenous fluorophore-biosensors can provide a fingerprint of tissue inflammation and architecture remodeling. The technology is very well suited for endomicroscopy using miniature needle objectives based on gradient index lenses [3].

Here, we present a compact multiphoton endomicroscope for label-free tissue imaging in small animals. The system consists of a galvanometric laser scanner, a femtosecond-pulsed fiber laser and a gradient index (GRIN) lens objective for endomicroscopy. An electrically tunable lens is implemented to facilitate fast shifting of the focal plane and acquisition of 3D volume stacks in live tissue. The setup is entirely rack-mounted and easily transportable between laboratories and animal facilities. Our endomicroscope can show the tissue morphology of unlabeled mouse colon with single cell resolution and can image tissue in three dimension to a depth of ~100µm based on cellular autofluorescence and *Second Harmonic Generation* from collagen.

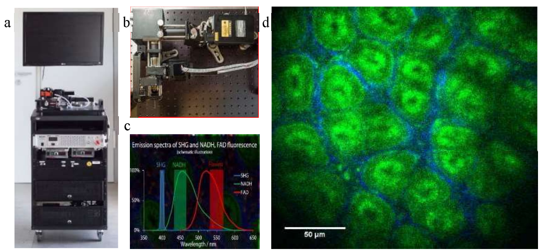

Figure 1: (a) The portable endomicroscope; (b) Multiphoton laser scanning system; (c) Endogenous fluorophores; (d) *In-situ* label free image from a dead mouse colon taken within three hours showing the colonic crypts and collagen.

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On the integration of Raman spectroscopy to multiphoton endo-microscopy for label-free optical diagnostics of colon cancer

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Colorectal cancer is the third most common type of cancer and widely spread in industrial countries [1]. The key to combat this futile disease is a successful diagnosis at the earliest stage possible. In this regard, the label-free optical technologies 'multiphoton endomicroscopy' and 'Raman spectroscopy' can offer some potential. Multiphoton imaging exploits non-linear properties of tissue samples for histology-like, optical sectioning [2]. The technology of multiphoton imaging has already been transferred to endoscopic settings and we just finalized engineering of such a multiphoton endomicroscope prototype, based on miniaturized galvanometric scanning principle and GRIN objectives. Raman spectroscopy on the other hand, relies on inelastic scattering by molecules with rotational and vibrational energy bonds [3]. It is molecule-specific but requires sophisticated processing algorithms to subtract undesirable fluorescence background in biological samples. Here, an *ex vivo* mouse model was investigated by Raman spectroscopy. The aim of this study was to monitor changes in the biochemical composition of mouse colon samples during tumor development induced by ulcerative colitis.

A new metrology, a data processing algorithm for background correction and a machine learning classification were designed. Preliminary results suggest that the Raman signal is reliable and that detected Raman peak positions match very well to the ones of comparable studies. Importantly, the spectral differences between cancerous, inflammatory and healthy tissue alone seem not yet sufficient to enable a successful automated differentiation. However, it is suggestive that the correlation between Raman spectroscopy and other bio-sensing techniques such as multiphoton imaging, stereomicroscopy or standard histology will lead to more reliable classification rigor. Finally, the concept of a hybrid system is suggested, combining multiphoton endomicroscopy with Raman spectroscopy to one single device. Based on the existing setups, its implementation is feasible and can overcome most of the limitations that are currently preventing automated bowel cancer detection.

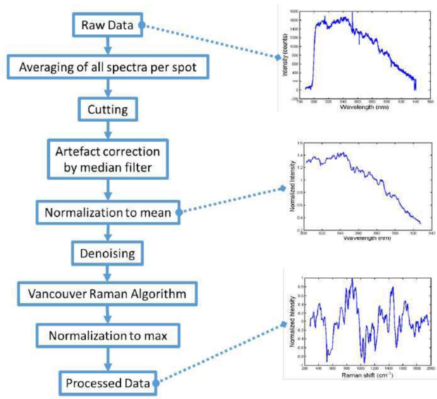

Figure 1. Data processing procedure for the Raman spectra from raw data until baseline corrected Raman signal.

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triSPIM: light sheet microscopy with isotropic super-resolution

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We propose a three-objective light sheet microscopy geometry capable of isotropic super-resolution imaging in mesoscopic samples [1]. An inverted geometry using 0.8 NA objectives ensures that this system is compatible with imaging samples mounted conventionally on cover slips, while providing high innate resolution. We first describe an excitation scheme, Maximally ORthogonal Detection-Excitation Nanoscopy in Thin Sheets (MORDENTS), in which skewed lattice light sheet excitation through multiple objectives is used in combination with computational image fusion to produce volumes with ~240 nm isotropic resolution in EGFP imaging. We then describe a second excitation scheme, Twinned-MORDENTS Requiring Interfering Lattice Light Sheets (TRILLS), in which simultaneous coherent excitation through two objectives is used to further substantially increase resolution, providing an isotropic lateral resolution of ~120 nm combined with ~190 nm axial resolution for EGFP imaging.

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